National Aeronautics and
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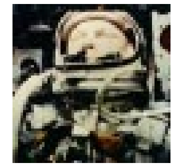
John Glenn
Biomedical Engineering Consortium
Helping Astronauts, Healing People on Earth



A Field Guide for Fitness

A new prototype portable device will measure human metabolic function at sampling rates previously unobtainable. Astronauts will be able to wear it during exercise in space. The same device may prove useful to exercise physiologists here on Earth, as metabolic function is a much better measure of fitness than heart rate alone.

Like all of us on Earth, astronauts need to keep fit. In fact, it is even more important for astronauts because their bones, muscles, and heart can weaken in space without the effects of gravity. This weakening is a medical concern when they return to Earth. NASA therefore continually evaluates the fitness of its astronauts, particularly during their longer missions in space, as on the International Space Station (ISS).

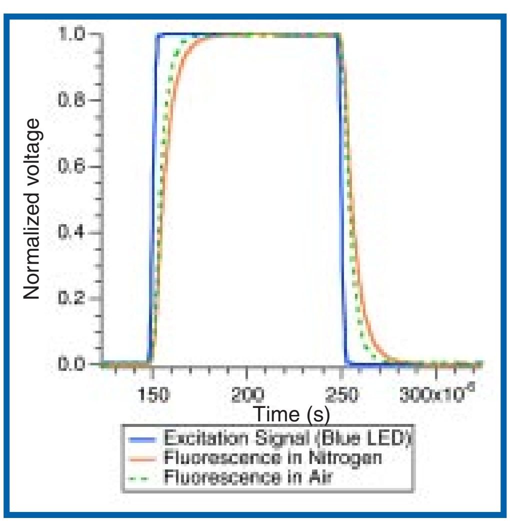
With the support of the John Glenn Biomedical Engineering Consortium (GBEC), principal investigator Daniel Dietrich of Glenn Research Center (GRC) and co-investigators Nancy Piltch (GRC), Marco Cabrera (Case Western Reserve University), and Peter Struk and Richard Pettegrew (National Center for Microgravity Research) are developing a portable device that will quantify metabolic function by measuring temperature, flow, and pressure during respiration. This device will facilitate measurements during varied crew activities, and possibly extravehicular activities, and wirelessly transmit the results in real time to a remote storage or communication device. Data will be collected at an unprecedented rate, capable of resolving the metabolic activity many times during a single breath. At present, metabolic function on the ISS is measured with a large, stationary set of instruments to which the crew must be attached with tethers.

Measuring human metabolic activity is very important for medical investigations in space and on Earth. One primary measure of clinical interest is energy expenditure, which can be determined by direct calorimetry, measuring a subject's energy release rate. This requires very specialized equipment and an isolated and resting subject. It is therefore impractical in many clinical settings, including a space-based platform.

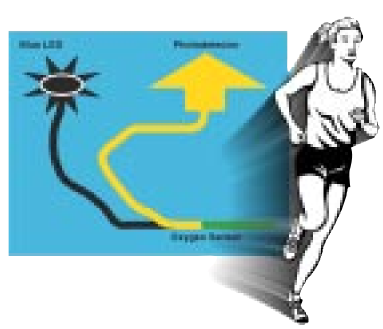
The other method of measuring energy expenditure is by indirect calorimetry. This requires the measurement of the volumetric flows of oxygen and carbon dioxide. The energy expenditure EE (kilocalorie per day) is then computed from the Weir equation:

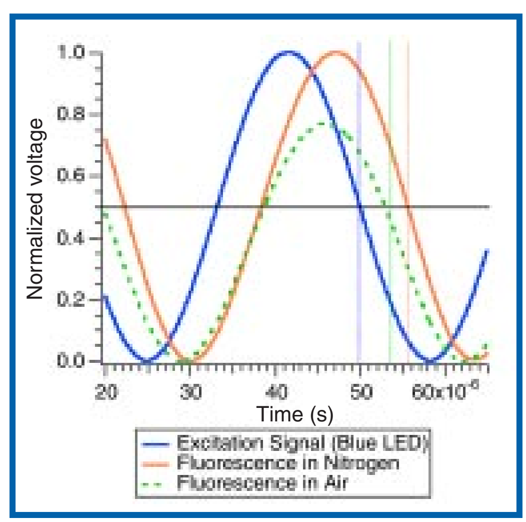
$$EE = [(3.491 * V_{O2}) + (1.11 * V_{CO2})]\ 1440$$

V_{O2} and V_{CO2} are the volumetric flows of oxygen and carbon dioxide (in liters per minute at standard temperature and pressure). Another important quantity in evaluating fitness and nutritional



Physical principle.





Preliminary measurements.

programs is the respiratory quotient RQ:

$$RQ = [\, V_{CO2} / V_{O2} \,]$$

RQ varies in humans between 0.67 and 1.3. Its value is a function of the combination of carbohydrate, fat, and protein used for energy.

The above relations require accurate measurements of oxygen and carbon dioxide mole fractions, temperature, pressure, and flow rate. Advances in a wide range of technologies, from sensors to miniaturization, are facilitating the design of increasingly small devices for measuring physical quantities. For instance, pressure and temperature sensors are now routinely incorporated into wrist watches (that also tell time), and small optical sensors can detect increasingly low-level signals and measure their variations over a wide range of wavelengths, at higher temporal frequencies, without bulky amplification devices.

The metabolic sensor project will exploit these advances in technology to develop a portable instrument that measures human metabolic quantities such as breath temperature, flow, and pressure. The prototype device will also measure the concentration of two of the most important gases to human metabolism, oxygen and carbon dioxide. Technologies already exist that are sufficiently miniaturized for incorporation into a portable device; even devices fabricated using micro-electromechanical systems (MEMS) technology may be included to perform these types of measurements.

The device will have new oxygen sensors using materials that fluoresce orange when excited by blue light. Oxygen quenches the fluorescence process, with the degree of quenching related to the amount of oxygen. The new probe will be fabricated as an optical fiber coated at the tip with a polymer containing the fluorescing material. This probe could be quite small, suitable for portable devices. Building upon a commercially available sensor, the consortium researchers plan improvements in the technique and data analysis to maximize the measurement accuracy and minimize concerns about contamination, drift, and calibration.

Measurement of carbon dioxide will be based on existing technology that takes advantage of the strong and unique infrared absorption characteristics of the carbon dioxide molecule. This relatively mature, robust technology forms the basis of automobile emissions testing. Recent advances in miniaturization of infrared emitters and detectors allow the subsystem that measures CO_2 to be made into a unit roughly the size of a fingertip. The other metabolic measurements (inhalation and exhalation gas temperature, pressure, and flow) will all be based on existing technologies.

Benefits on Earth

Human metabolic function is a much better evaluation of fitness and the effectiveness of fitness programs than a heart rate by itself. People who are being rehabilitated after heart attacks or other illnesses could use a portable metabolic measurement device to monitor their physical response to exercise. Athletes, and anyone else who wants to stay fit, could increase their endurance by making sure their workout keeps them working at the top of their capacity.

For more information about the John Glenn Biomedical Engineering Consortium or consortium projects, please contact

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